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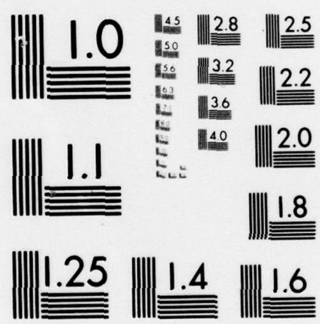

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on

Some Engineering Problems in the Royal Air Force

by

H.Durkin

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SOME ENGINEERING PROBLEMS IN THE ROYAL AIR FORCE

by

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Controller of Engineering and Supply (RAF)
Ministry of Defence (Air)
Old War Office Building
Whitehall, London, UK

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- Improving the co-operation among member nations in aerospace research and development;
- Providing scientific and technical advice and assistance to the North Atlantic Military Committee in the field of aerospace research and development;
- Rendering scientific and technical assistance, as requested, to other NATO bodies and to member nations in connection with research and development problems in the aerospace field;
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FOREWORD

The Structures and Materials Panel of the Advisory Group for Aerospace Research and Development (AGARD) is composed of scientists, engineers and technical research and development administrators from industry, universities and governments of the NATO nations. It is concerned with advancing the status of aerospace research and development and developing technical means and data for optimizing the vehicles and equipment of interest to NATO. The Panel, therefore, provides a discussion forum, a mechanism for exchange of information, and a means of stimulating, establishing and conducting cooperative technical efforts in selected areas.

The Structures and Materials Panel normally meets twice-a-year to conduct its business. The meetings are held in the various NATO nations at the invitation of the respective governments. On these occasions it is customary for a representative of the host nation to address the Panel and to provide a view, from his perspective, of status, needs, trends or activities on technical matters related to research and development relevant to Panel interests.

The address made by Air Marshal Sir Herbert Durkin at the meeting in London of the Structures and Materials Panel September 1976 is contained herein. In this presentation, Air Marshal Durkin provides a valuable reminder to the research and development community of the importance of a variety of qualities required in air vehicles for satisfactory performance in service. Although reliability and ease in maintenance are tacitly accepted as requirements they have tended to get less attention from the research and development community than the more alluring goal of ever higher performance. Air Marshal Durkin's wholesome reminder should provide a needed stimulus toward achievement of an appropriate balance of research and development goals.

T.F.KEARNS
Chairman, Structures
and Materials Panel

SOME ENGINEERING PROBLEMS IN THE ROYAL AIR FORCE

by
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SUMMARY

The Engineer and Supply Branches of the Royal Air Force are responsible for maintaining all the complex and expensive aircraft and equipment in the service, an operation costing some £700m annually. The RAF is constantly striving to reduce the cost of its engineering and supply support, and increase its effectiveness.

This paper describes some of the current problems of the RAF related to the structural and materials areas, and indicates the improvements sought in the fields of reliability, maintainability, structural integrity, design, inspection, corrosion and battle damage.

INTRODUCTION

In spite of reductions over the past years, the Royal Air Force is still one of the largest single employers of manpower in Britain. It still operates widely overseas, although its main commitment is to NATO and Central Europe. The RAF is required to operate and therefore maintain its aircraft not only from prepared bases but also with mobile forces from places with very limited facilities. The equipments which we maintain vary from complex aircraft and their weapon systems, through all types of ground and airborne radars, communications systems, guided missiles, armament, photographic reconnaissance equipment and all the associated ground support equipment, to motor transport and marine craft. The Royal Air Force continues to operate aircraft in every role, concentrating all its operational activities within the UK in Strike Command, which was formed from the older Bomber, Fighter, Coastal and Transport Commands. It operates an inventory of 35 different types and 72 marks of aircraft; it will be appreciated that the difference in marks in many cases is very significant in the engineering context.

The Royal Air Force's equipment is complex, expensive and, unfortunately, prone to unreliability. Maintenance is therefore a formidable task. A vast range of spares has to be bought, stored and managed, and a large repair organisation maintained both within the service and within industry. Some £700 million annually is spent on our engineering and supply support.

The supply inventory necessary to support our tasks totals some 1.3 million items of technical equipment, and, despite our reducing numbers of aircraft, this inventory continues to grow at a rate of about 3% annually, which indicates the increasing complexity of equipments entering the service. There has been a considerable degree of rationalisation of support between the three services. For example, the RAF looks after the supply of all aircraft spares for both the Army and Navy and is responsible for the storage and repair of fixed-wing aircraft for all three services.

Manpower is, of course, one of the Royal Air Force's most important resources. Personnel costs are ever rising, but more expenditure in this area means less to spend on new aircraft and equipment.

With that background, it is now appropriate to examine areas which are of concern from a structural and material viewpoint.

MAINTAINABILITY AND RELIABILITY

The RAF requires improved reliability and maintainability for two main reasons: first, because its role is to provide air power wherever and whenever it is needed and to maintain a high state of readiness, and second, because of the very large contribution which maintenance costs make to the cost of ownership of an aircraft or equipment.

As the size of the RAF has decreased, the need for greater reliability has increased because every weapon system must be sufficiently reliable to meet its operational task. Confidence in reliability should ultimately allow reduction of the initial buy of aircraft necessary to meet a given operational task, and so lead to economy.

The contribution of maintenance costs to the cost of ownership is shown in Fig. 1,

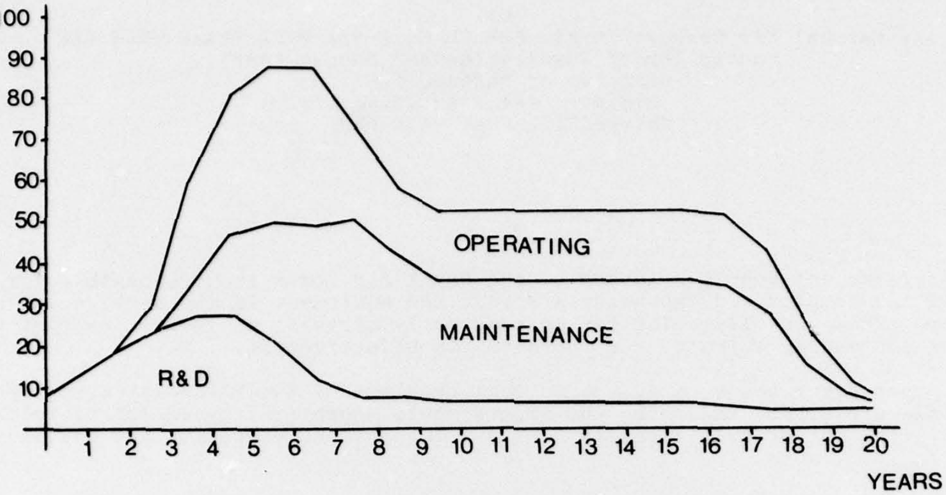

Figure 1. Estimated Distribution of Costs Through Life Cycle

the Life Cycle Cost for a typical aircraft over a 20 year period. It is divided into research and development, and operating and maintenance costs; production costs of the aircraft are included under operating costs.

The RAF is exploring a number of ways of improving reliability, but it accepts that the continued introduction of new equipment of improved performance and increased complexity make some shortcomings in reliability unavoidable. As a counter, the RAF must strive also for greater maintainability. In this way servicing, be it scheduled servicing or rectification, can be accomplished in the minimum time to enable rapid recovery to a serviceable state. Precautions are also needed to eliminate every possible source of servicing error in the field. Servicing and rectification in a heated factory or hangar can be very different from servicing an aircraft in the open at night in the biting wind of an arctic winter, and with only a torch for illumination.

There are several areas in which action is in hand or which are being studied. First, research and development establishments are being involved in reliability and maintainability. Up to now, research has tended to concentrate solely on performance improvements. Second, quantitative reliability and maintainability parameters are being specified in the operational requirement and specification, and at least some of these require to be demonstrated. In the case of the Hawk trainer now under development, an incentive contract has been agreed with Hawker Siddeley which is tied both to verification of defect rates after the aircraft has been in service for some two years, and to a demonstration of maintainability. Third, the Royal Air Force's interest in maintenance and reliability starts at the conceptual stage of new projects and its aim is to influence design and equipment selection to embrace these two vital factors. To achieve this, the Central Servicing and Development Establishment, manned by RAF Engineering Officers and SNCOs, provides a direct link with design staffs through teams that are normally resident at the contractors works from the onset of a project. These teams, which are supported by the RAF Maintenance Data Bank and a wide variety of engineering specialists, give the designer up-to-date information of our maintenance policies and the extent of our engineering capabilities. Furthermore, they provide historical data and a high degree of practical engineering experience on systems and components that are in service with the Royal Air Force. Thus the RAF aims to ensure that "history does not repeat itself" as far as past problems are concerned.

This organisation provides the service with foreknowledge of the facilities, equipment, and skills that will be needed to operate a new aircraft type or a new system. A two-way flow of information, between the potential "user" on the one hand and the designer on the other, leads to great improvements in reliability and maintainability. The work is not confined to UK projects; the RAF has had teams on the Anglo French helicopters and on the Jaguar. At this moment, there are teams in five different locations in the United Kingdom, and in Germany and Italy dealing exclusively with the Tornado. Our colleagues in Germany and Italy have formed similar teams and they work on a fully integrated basis.

Fourth, attempts are being made to improve knowledge of how equipment is used in practice. This often differs very significantly from the way in which designers may have assumed their equipment will be used. Fatigue monitoring is a major consideration in this area. Similarly, it is clear that engines are cycled, particularly in the air defence and ground attack roles, more frequently and in a more random fashion than has been assumed in the past. A recent exercise on the engines which power our Phantoms showed the variation in cycles which can occur on apparently similar operations. Aircraft sortie patterns also change over the years and certainly the sorties are not always those reflected in the specification. Such changes may have considerable effects on either fatigue life or engine life. Accordingly, Statements of Operating Intent have

recently been introduced for a number of aircraft, and these give the current sortie patterns which are used for the purpose of fatigue consumption calculations.

Education programmes have been started to ensure that, where feasible, the operators know the effect of usage on their equipment so that they may be encouraged to conserve life. Easily readable booklets have been produced on fatigue and to emphasise the impact of engine handling on engine life. The RAF is expanding the use of what we term flexible take-off thrust techniques, whereby only that power needed for the particular circumstances in terms of take-off weight, runway length, and so on, is used. Also in the Vulcan we have installed a cockpit read-out from the fatigue meter so that the crew can change their sortie pattern, where they have the option, in order to conserve fatigue life.

Last, on this topic of efforts to improve reliability and maintainability and to reduce the cost of ownership is, of course, the importance of feedback of defect data. Since 1972, a first generation computer has been operating at the RAF Maintenance Data Centre. The Centre is responsible for collecting and processing reliability and maintainability data on all aircraft in service in the RAF and Royal Navy; the information is fed back by despatching to the centre coded duplicates of the job card on which the rectification work is recorded. Over 100,000 of these job cards are received every month. They are supplemented by narrative reports on major defects as well as by a comprehensive flight safety accident and incident reporting system. Since over £200m each year is spent on the rectification of defects, our managers must be provided with a good information service if this cost is to be minimised. The services which are now being obtained include: a regular feedback to RAF engineering authorities of reliability statistics and defect data in which the most costly defects are highlighted in order to assist in deciding on priority areas for remedial action; the provision to industry of similar data not only so they may know how their equipments are performing in service but also to guide them in the design of equipment for new aircraft; an interrogation service to the users and to industry and the case history on the more serious defects as required; data on rectification manpower expenditure; logistic information for provisioning purposes and as a basis for assumptions for our mathematical modelling techniques; and a computer based method of calculating refined fatigue consumption for each aircraft and to provide a fatigue data bank.

The system as a whole has now gained the confidence of both the user in the service and in industry. It has certainly proved to be a significant advance over the earlier manual system.

The Centre occupies the time of some 200 personnel and costs about £1m per annum to run. Until now we have gathered information directly from operating units and assembled it into the central data bank. By so doing unit managers and headquarters' staffs may be by-passed. It is felt that the eventual engineering management information system should allow all levels of management direct access to the information which applies to their fields of interest. A new computer system is being studied, to replace our present computer in about 1980; small computers at stations and at Command headquarters may perhaps talk directly to a central computer.

STRUCTURAL INTEGRITY

Fatigue and structural integrity are areas to which the RAF is paying considerable attention. Until fairly recently, military aircraft design has put an extremely high premium on operational performance and only safety approached an equal priority in the consideration of design compromises. Soaring costs of procurement have led to requirements for longer lives in service to maintain viable numbers of aircraft in the front line. Over the last few years, smaller and smaller numbers of aircraft have also led to greater emphasis on measures to improve the availability of aircraft to fly, ie, less servicing and higher reliability of aircraft and systems. As an example of this trend, the 1000 odd Meteors introduced into the RAF in the 50's had an average life of 10 years during which they flew an average 800 hours, compared with requirements now for 20 years and 4500 flying hours for the very much smaller force of Lightnings. In this example not only is a longer life sought but during the life an average utilisation is required equal to over twice the flying hour rate per annum for the Meteors. Lives of up to 8,000 flying hours per aircraft are now being contemplated; indeed a far cry from the war years when 300 hours was the maximum achieved by a combat aircraft.

Fatigue damage is of primary concern. It has been policy for the past 25 years to fit all RAF combat aircraft with fatigue meters, (more correctly, counting accelerometers measuring exceedances of normal acceleration levels at the centre of gravity of the aircraft). The fatigue meter readings are used in an approximation of Miner's Law to give an indication of fatigue damage occuring in individual aircraft. This monitoring, in conjunction with a full scale fatigue test, is an essential element in the Royal Air Force's structural integrity programme.

Structural unreliability is clearly expensive and the Royal Air Force sees its objectives as being:

a. A structure which will not fail catastrophically or even uneconomically during the life of the aircraft. This requires:

b. Improved forecasting of timing and location of possible defects.

c. The ability to assess the likely progress of defects once identified and the residual strength of defective structures.

d. Easy economical repair.

e. Resistance to battle damage.

If these objectives are to be achieved there is a need to change RAF design philosophy from safe-life to damage-tolerant, and to identify much more closely realistic load spectra under service conditions, not only in the air but also on the ground. At present there is insufficient information available to devise a realistic load spectrum for some wing skins, fins and tailplanes, rear fuselages, undercarriages and helicopter transmission units. Fatigue life estimation accuracy is suffering from ignorance of service spectra. These are not the only areas where knowledge is very scanty, but improved knowledge in this field should both increase the realism of full scale fatigue tests and improve our ability to relate the experience of individual aircraft to these tests. The first move towards realising an improvement is the introduction of "Statements of Operating Intent", mentioned earlier; their intention is to tell the operator the assumptions made by the designer on how he thought the aircraft were to be flown in service. They also tell the designer how the aircraft are actually flown in service. In some cases the two are proving to be radically different. Our present fatigue meters are also being examined critically. The degree of interest now being given to the way that combat aircraft are actually used in service has focussed attention on the short-comings of the simple compromise offered by a single fatigue meter. This method was developed to monitor the wing/fuselage interface. Correlation with changing wing positions, as in the Tornado, and the high loadings associated with fin and tail surfaces during high speed manoeuvres, becomes increasingly difficult. Also, as the fatigue meter only measures air loads, ground load damage cannot be monitored. This is significant when it is realised, for example, that some 80% of the fatigue damage to the upper surface of the C130 mainplane occurs during the ground-to-air, air-to-ground cycle.

DESIGN CONCEPT

Unfortunately, it seems to the RAF that while the nominally safe life aircraft have had a fair degree of damage tolerance in the past, new aircraft will be markedly less so because of design trends such as:

a. The use of monolithic structures with lower crack stopping capabilities.

b. The use of high strength alloys with lower toughness and greater variability in material properties.

c. The use of computer aided design resulting in lower hidden reserves of strength and structure optimised for weight saving rather than reliability.

Since economy, reliability and resistance to fatigue and battle damage are our aims, we are strongly supporting the adoption of a damage tolerant design philosophy compared to our previous safe life approach. The Tornado is likely to be the last "Safe Life" aircraft to see service with the RAF.

INSPECTION

Whether the aircraft is a safe life or a damage tolerant design the maintenance organisation needs to know where to look to find defects, and when. Today, inspection intervals for structures in service are arbitrary. The trend towards on-condition maintenance pursued in the 60's went too far. After examining the background to a number of serious unexpected structural failures which caused accidents, the conclusion was reached by our structural integrity working party that:

> "Experience on different types of aircraft amply demonstrates that past methods of design, construction and servicing do not preserve acceptable standards of integrity of the structure throughout its life".

The RAF has therefore adopted the principle that all structure must be inspected during its life and the design must permit such inspection. Another important problem is what standards should be applied to decide whether to monitor, repair, or replace a defective element found during inspection? Is it possible to build in to the structure failure warning systems like the gas leak crack detection BIM system in helicopter blades which has proved so useful in dealing with a recent failure? Is it possible to detect, for example, a propagating crack before it becomes catastrophic, preferably both while the aircraft is in flight and when it is stationary on the ground? Are there any special characteristics surrounding a crack tip which can be detected in a defective structure? Acoustic Emission springs to mind, but are there other characteristics which might be measured and monitored? At the moment, servicing organisations rely mainly on the eye supported by experience and training; it is not enough.

The RAF Non Destructive Test teams do their best, but they still need to have the location and nature of likely defects fairly closely defined before NDT can be used. This is where fracture mechanics research or the development of large scale NDT search techniques may be able to help and the RAF wholeheartedly supports the research in this field.

CORROSION

Corrosion is one the most persistent defects recurring in each generation of military aircraft. Not so long ago, when the required life of RAF aircraft was only a few years, corrosion was not a major problem. However financial constraints now require the aircraft to be retained beyond their initially projected lives. For example, the Canberra has now been flying for 25 years and may be required to fly for a good many years yet. Consequently, protective treatments applied during production become progressively less effective with time, and with the minor accidental damage which is bound to occur in service an increase in the incidence of corrosion may be expected.

The Royal Air Force view is that its corrosion problem has two sources. First, there have been errors in design and production, whilst second, RAF maintenance practices have been geared in the past to the rectification of corrosion rather than its prevention. Experience shows that designers have sometimes not given sufficient attention to the overall properties of new materials selected to achieve increased strength/weight ratios with the result that we have paid dearly for subsequent corrosion rectification. In particular, the magnesium alloys and the exfoliation-prone high strength aluminium-zinc alloys have given trouble. Strict controls have now had to be placed on their use. However the RAF will still have to live with this problem on some existing aircraft for many years to come. There have also been many examples of poor detail design or manufacturing procedures, such as inadequate consideration given to the specification of protective treatments, particularly between dissimilar metals, and errors in their application during production. There has also been unsuitable use of materials for the environment in which they must function and there has been inadequate provision made for draining or venting of all parts of the structure. In spite of all precautions, corrosion still occurs, and to minimise these problems it must be detected and rectified as early as possible. The golden rule must be "prevention is better than cure". A new code of design practice has been prepared and recently issued in the form of chapter 801 in the design requirements for military aircraft, AvP 970. These requirements demand that access should be provided to inspect all primary structure either with or without visual aids such as endo-probes. They also require protection of internal and external surfaces and the use of "wet assembly". The RAF is convinced that wet assembly has made a considerable contribution to delaying the onset of corrosion; that is, all faying surfaces have some sealant applied before assembly.

The most recent Air Staff Target specified a normal corrosion free life of over 15 years with a minimum number of corrosion prevention manhours. Our inspection policy is designed to detect corrosion and damage to protective treatments at an early stage so that remedial action can be taken. The preventive measures adopted may be summarised as follows:

a. The aircraft are kept clean by regular washing.

b. The aircraft are kept dry in hangars wherever possible and

c. Their protective coatings are maintained in good condition.

One of the problems is the time taken to rectify protective finish which has been locally damaged, time that can be ill afforded when the aircraft is required for flying. Procedures are therefore being introduced for the application of temporary protectives. Kits containing touch up quantities of paints, protectives and sealants are being introduced so they may be applied to minor surface damage whenever it is found. A corrosive fluid decontamination kit is also being introduced for carriage in all transport aircraft so the aircrew may neutralise any accidental spillage of dangerous cargo which, regrettably, still occurs. Finally, as all these measures will be wasted if the aircraft engineering tradesmen are not motivated, they are receiving advanced training in the practices of corrosion prevention and control, the aim being to acquire a corrosion awareness so that the well-informed tradesman will recognise and forestall the onset of serious corrosion.

BATTLE DAMAGE

During the re-appraisal of our war posture from the nuclear trip-wire concept to one of flexible response, it became clear that a conventional tactical conflict would need to be fought before escalation to an all-out war took place. Renewed emphasis is therefore necessary on the ability of NATO air forces to recover quickly from battle damage which, although not sufficiently severe to prevent the aircraft's return to a friendly base, will prohibit its use on further missions until a measure of repair has been done. This need for rapid recovery of damaged aircraft will require new concepts to be adopted within a safety conscious peace-time air force. These may be in conflict with present methods of repair and will require strong motivation, good training and firm logistic support if they are to be effective after a rapid transition to war.

The importance of aircraft availability is well established but the degree of damage resistance, minimum acceptable airworthiness standards and urgency of repair, all balanced against operational capabilities and financial cost, are unknown. Modern aircraft have been required to meet more demanding performance requirements whilst improved design and production techniques have led to less damage tolerant structures. For these highly stressed aircraft, peacetime safety needs ensure that repair schemes are individually tailored by design authorities to restore the full static and fatigue strength of the structure and with correct corrosion protection measures, with little regard to the time

and manpower utilised. Such procedures are incompatible with the tempo of a European war. Furthermore, wartime types of damage are unlikely to fall within our peace-time experience. There is much to be done to improve our techniques if current aircraft are to be returned quickly into battle following unacceptable damage.

CONCLUSIONS

This paper has been a broad look at the RAF and some of its problems. It gives some idea of the very challenging and satisfying work which faces an engineer in the RAF today and has indicated how, within the constraints of ever-mounting pressure on defence expenditure, the Royal Air Force is trying to ensure that it maintains and, indeed, improves upon its already high standards of effectiveness, safety and airworthiness. Engineering and supply support plays a vital part in maintaining the Service at the efficiency which is essential not only to the effective defence of the UK but also to the support of its allies in NATO and elsewhere.

Structural and material engineers carry a heavy responsibility to ensure that NATO gets the aircraft which will do the tasks demanded of them in the safest and most economical manner.

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14. Abstract

In this presentation, Air Marshal Durkin provides a valuable reminder to the research and development community of the importance of a variety of qualities required in air vehicles for satisfactory performance in service. Although reliability and ease in maintenance are tacitly accepted as requirements they have tended to get less attention from the research and development community than the more alluring goal of ever higher performance. Air Marshal Durkin's wholesome reminder should provide a needed stimulus toward achievement of an appropriate balance of research and development goals.

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Reliability
Service life
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Project planning

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Advisory Group for Aerospace Research and Development, NATO
SOME ENGINEERING PROBLEMS IN THE ROYAL AIR FORCE
H.Durkin
Published February 1977
12 pages

In this presentation, Air Marshal Durkin provides a valuable reminder to the research and development community of the importance of a variety of qualities required in air vehicles for satisfactory performance in service. Although reliability and ease in maintenance are tacitly accepted as requirements they have tended to get less attention from the research and development

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